Sustainability Indicators for Biogas Production from Palm Oil Mill Effluent: A Case Study in Indonesia

Fentinur Evida Septriana, Tri Edhi Budhi Soesilo, and Ahyahudin Sodri

Abstract The sustainability assessment of the biogas production from palm oil mill effluent is complex, so it requires indicators that represent the sustainability concept of the system. This study aims to determine sustainability indicators of the biogas production system from palm oil mill effluent using the participatory analytic hierarchy process. This study results in ten sustainability indicators, in order of importance, consisting of the availability of raw material, profitability, greenhouse gases emissions, energy efficiency, water usage, production cost, investment, installed capacity, residents benefits, and job creation. These indicators help evaluate the sustainability of the biogas production system from palm oil mill effluent in the Bangka Belitung Islands and other regions in Indonesia.

Keywords Sustainability indicators · Renewable energy system · Biogas production · Palm oil mill effluent · Analytic hierarchy process

1 Introduction

Biogas from Palm Oil Mill Effluent (POME) has been recognized as a renewable energy source that helps meet energy needs together with the wastewater treatment to reduce water pollution and greenhouse gases (GHG) emissions. In Indonesia, biogas production from POME has been carried out in several places, one of which is in the Province of Bangka Belitung Islands. Over the years, the palm oil industry together with the refined tin industry have dominated the processing industry sector which accounts for nearly a fifth of the gross regional domestic product in the Bangka Belitung Islands, becoming the largest contribution to the economic

F. E. Septriana · T. E. B. Soesilo (✉) · A. Sodri
School of Environmental Science, Universitas Indonesia, Jalan Salemba Raya 4,
Jakarta, Indonesia
e-mail: soesilo@indo.net.id

A. Sodri
e-mail: ahyahudin.sodri@ui.ac.id

L. Yola et al. (eds.), *Sustainable Architecture and Building Environment*,
Lecture Notes in Civil Engineering 161,
https://doi.org/10.1007/978-981-16-2329-5_15

structure [1]. Several palm oil mills that produce large amounts of POME are combined with biogas plants that produce biogas from POME to generate electricity sold to the State Electricity Company. It supports local government efforts to increase the use of electrical energy from renewable energy sources. The production of biogas from POME is a form of renewable energy system. Therefore, to facilitate sustainable development planning that considers the needs of the current and future generations [2], especially in renewable energy development, it is necessary to know the sustainability of the biogas production from POME.

The concept of sustainability is very appropriate to be applied to complex problems because it integrates cross-sectoral aspects and involves multidisciplinary sciences. Sustainability assessment is complex because it requires interacting multidisciplinary aspects [3]. Solving the complexity of the sustainability of renewable energy systems requires indicators that can reflect the integrity of the system and the interaction of its subsystems [4]. Assessment of the sustainability of renewable energy systems must be able to explain system performance [5], which can be done by evaluating parameters that represent the integral concept of sustainability [4]. Thus, these sustainability indicators are truly valid and reliable to measure the sustainability of renewable energy systems. The main objective of sustainability indicators is to provide a framework for sustainability assessment that is driven by comprehensive, scalable, relevant, and easy to understand information [6].

Indicators are representative symbols used to explain trends in complex entities or systems [6], such as the sustainability of energy systems. Assessment of the sustainability of energy systems generally requires the use of resource, environmental, social, and efficiency indicators [4]. The use of various indicators is necessary to support the decision-making process related to energy sustainability policies. The sustainability of the renewable energy system, in principle, refers to the performance of the system in environmental, economic, and social aspects [7], so that at least these three aspects are involved in the sustainability assessment.

The process of selecting indicators requires parameters associated with reliability, compatibility, practicality, and measurement limitations [8]. Basically, the indicators for the sustainability of the renewable energy system must be able to reflect the concept of sustainability, measure the quality that is in line with sustainability objectives, be based on current and reliable information, reflect strategic views, provide a reference for system optimization, and reflect longevity of the system [4, 5].

Several studies on sustainability indicators of renewable energy systems have been carried out before. Studies in Indonesia have been carried out for bioenergy sustainability indicators [9], which was followed by recommendation of Indonesian Bioenergy Sustainability Indicators (IBSI) through several focus group discussions [10], and determination of sustainability indicators for palm oil-based bioenergy [11]. However, the specific sustainability indicators for the biogas production system from POME have not been determined. Furthermore, most of the studies on sustainability indicators of renewable energy were carried out in developed countries, even though the use of renewable energy was being increased in developing countries.

This study aims to determine the sustainability indicators of the biogas production from POME that can be used to evaluate the sustainability of the system through the model that will be developed. The results of this study are useful for assessing the sustainability of the biogas production system from POME in the Bangka Belitung Island, Indonesia.

2 Methods

Multi Criteria Decision Analysis (MCDA) is considered as the most suitable method for solving problems related to energy issues, considering that decision making on energy issues usually consists of many actors and many criteria that have several objectives [12]. Analytic Hierarchy Process (AHP) is one of the MCDA methods that breaks down general and uncontrolled problems into more specific and controlled sub-problems, then combines the solutions of all sub-problems into a conclusion [13]. Weighting the priority ranking using the AHP method is increasingly being used because of its easy-to-understand theory and simple application [8]. This study used AHP to determine the sustainability indicators for biogas production from POME.

This study was conducted in the Bangka Belitung Islands from August 2020 to October 2020. Sustainability indicators of renewable energy were identified from previous studies [5, 11, 14–16], then these indicators became the subject of focus group discussions (FGD). The indicators from the discussion results are then scored collectively by the FGD participants based on the criteria that have been determined in the discussion. Focus group discussions were held by involving representatives of stakeholders from two oil palm companies that have biogas plants, Energy and Mineral Resources Agency, Environment Agency, and State Electricity Company. The pairwise comparison matrices were used for weighting criteria and indicators. The weighting was carried out based on a rating scale of 1–9 according to Saaty [17]. In summary, the stages of the study taken are presented in Fig. 1.

3 Results and Discussion

The priority order of the sustainability indicators was determined based on the criteria determined in the FGD using a hierarchical structure as shown in Fig. 2. The criteria for the sustainability indicators to be assessed were determined through the FGD process, consisting of 7 criteria, namely relevance, measurability, informativeness, reliability, strategic, optimization, and long term. The sustainability indicators set for assessment through the FGD process consist of 10 indicators, namely investment, production cost, availability of raw materials, profitability, residents benefits, job creation, GHG emissions, energy efficiency, installed capacity, and water usage.

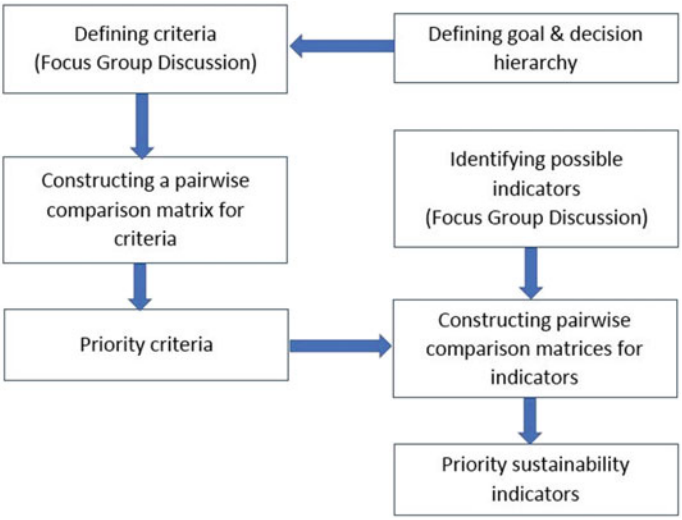

Fig. 1 The stages to determine sustainability indicators

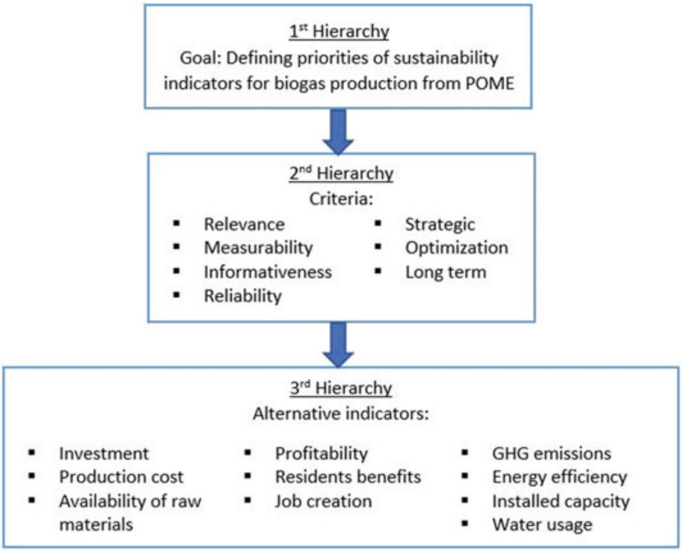

Fig. 2 Hierarchy structure to determine the priority sustainability indicators

The results of the criteria weighting with pairwise comparison matrix are presented in Fig. 3, with overall consistency ratio of 0.04. The "long term" criterion has the most important position compared to the other six criteria, followed by the criteria of relevance, measurability, reliability, informativeness, optimization, and strategic respectively. The "long term" criterion has the highest level of importance because the sustainability indicators of renewable energy must reflect the longevity of the system, in accordance with the concept of sustainability which shows the system's ability to survive, develop, and adapt to changes that occur in the long term [18].

Criteria with a lower level of importance were also needed to determine sustainability indicators at a later stage. Sustainability indicators must be relevant [5] to the renewable energy system being observed to be meaningful [19], easy to measure so that it facilitates the assessment process, reliable [5, 8], can inform the current system conditions (information is easy to obtain), can be used for system optimization [5], and strategic (related to several interests). The results of the criteria weighting in Fig. 3 were used to determine priority sustainability indicators which were also weighted using pairwise comparison matrices.

The results of indicators weighting for each criterion are briefly presented in Fig. 4. The consistency ratio of indicators weighting on the criteria of relevance, measurability, informativeness, reliability, strategic, optimization, and long term is 0.08, 0.04, 0.03, 0.05, 0.03, 0.05, and 0.03, respectively. The availability of raw materials has the highest level of importance compared to other indicators, in almost all criteria (except in "reliability" and "optimization"). In the "reliability" criterion, availability of raw materials has a slightly lower weight than production cost. This indicates that based on the stakeholders' view, production cost is more reliable in measuring sustainability than the availability of raw materials. In the "optimization" criterion, availability of raw materials has a slightly lower weight than energy efficiency. This indicates that based on the stakeholders' view, energy efficiency is more suitable to indicate optimization of the biogas production system from POME than the availability of raw materials. The results of overall weighting of sustainability indicators for the biogas production from POME, based on all criteria is shown in Fig. 5.

The sustainability indicator of renewable energy that was considered to be the most important by stakeholders is the availability of raw materials. This indicator is very important to measure the sustainability of the biogas production system from POME because based on their experience, the continuity of biogas production from

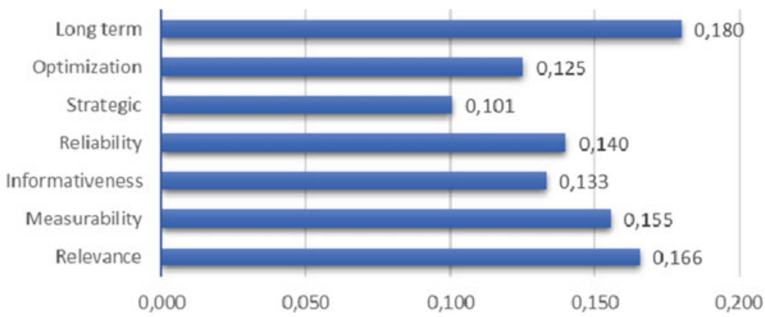

Fig. 3 Criteria importance weighting results

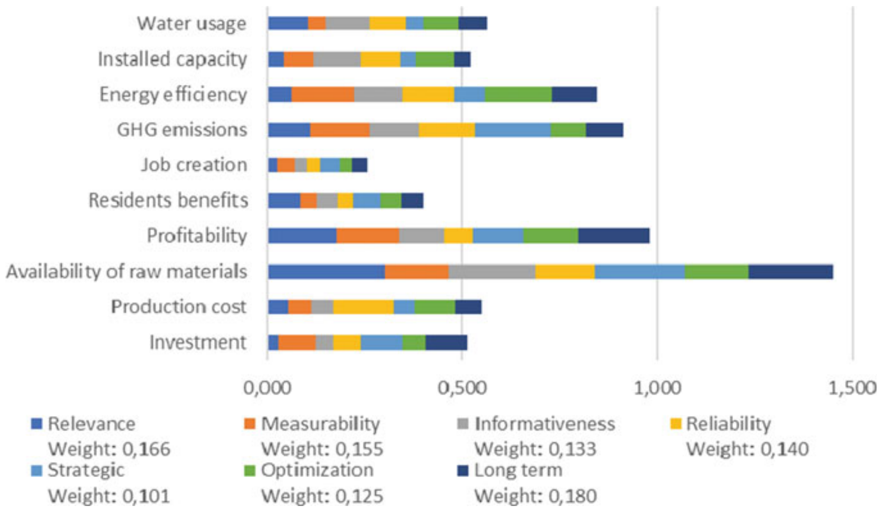

Fig. 4 The weights of the alternative indicators on each criterion

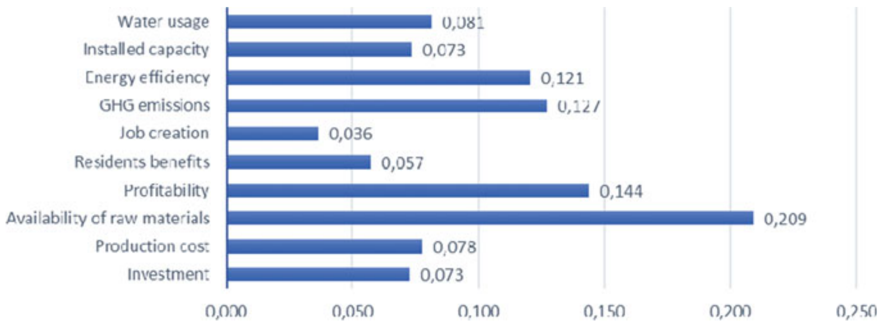

Fig. 5 Sustainability indicators importance

POME is very much influenced by the supply of POME from palm oil mills. The biogas production process cannot be sustainable if the available raw materials are very limited or only available at certain times. The production of biogas that is not continuous will cause the generation of electrical energy which is also not continuous and difficult to control. It will affect the sustainability performance of the biogas production system from POME as a whole. The availability of POME as raw material depends on the production process at the palm oil mill which process fresh fruit bunch. This raises the pros and cons of several parties because the fresh fruit bunch come from plantation land which is closely related to land use, regional spatial planning policies, issues of forest land conversion, biodiversity reduction, and greenhouse gas emissions.

The yield of oil palm plantations has decreased and has led to decreased production activities in palm oil mills in the Bangka Belitung Islands. As a result, POME, which is the raw material for biogas production, has also decreased. Thus, the palm oil industry also affects the availability of raw materials for biogas production from POME. Based on this condition, it can be understood if stakeholders view the availability of raw materials as the most important indicator of the sustainability of biogas production from POME.

Other indicators that relatively have high importance are profitability, GHG emissions, and energy efficiency. Profitability is one of the important factors affecting economic sustainability [16]. Profitability is important to be used as a sustainability indicator because it affects the ability to return capital. In addition, profitability can also reflect a company's economic ability to generate maximum profit, which is determined by the selling price and production costs. In the Bangka Belitung Islands, the selling price is largely determined by government policy factors and the sole buyer of electricity generated, namely the State Electricity Company, so that profitability is very important to be used as an indicator for measuring the sustainability of the biogas production system from POME, whose main function is to generate electricity.

In the environmental dimension, GHG emissions have generally been an indicator of the sustainability of renewable energy systems in various previous studies [11, 14, 15, 20–23] because it is closely related to the issue of world climate change. Biogas from POME is an anaerobic process product whose main component is methane gas so that biogas production is an effort to reduce GHG emissions in palm oil mills. The performance of the process in the plant is greatly influenced by energy efficiency. The efficient processes require lower capital and operating costs [14]. Energy efficiency can also reflect the wasting energy that occurs in the plant due to heat loss that is released into the environment. In a broad sense, renewable energy sustainability can be achieved if it is in line with the concept of energy efficiency [24], because the use of renewable energy and energy efficiency are two components that must be applied together [25].

The other six indicators (water usage, production cost, investment, installed capacity, residents benefits, and job creation) will still be used to assess the sustainability of the biogas production system from POME, although it has a lower weight. This weight will affect the portion of the system's sustainability assessment on the related indicators. The weighting results show the priority of indicators in the economic dimension over social dimension which indicate the stakeholders' priority in the formulation of policies planning related to the biogas production from POME. Based on routine reports on the implementation of environmental management and monitoring efforts by the company, the majority of residents around the site welcome the existence of the biogas plant (the plant location is quite far from residential areas), and many local residents are involved laboring in the biogas plant or palm oil mill. This reduces the concern of stakeholders to the social-community dimension. On the other hand, the selling price of electricity generated from biogas, which significantly affects the company's profitability, needs to be considered. As the results above, profitability significantly affects the sustainability of the biogas plant's process and the availability of raw materials that are highly dependent on operations in palm oil mills and plantations.

4 Conclusions

Sustainability indicators for the biogas production system from POME in the Bangka Belitung Islands were determined by the participatory AHP method, in order of importance, consisting of availability of raw materials, profitability, GHG emissions, energy efficiency, water usage, production cost, investment, installed capacity, residents benefits, and job creation. Based on the stakeholders' views, the availability of raw material is the most important indicator. The sustainability indicators will be used to assess the sustainability of the biogas production system from POME that will be modeled in further study, with the portion of the assessment being proportional to the weight of each indicator.

Stakeholders place the economic dimension above other dimensions, based on their experience which shows that economic factors often hamper the continuity of biogas production than other dimensions. This does not mean that other dimensions are not considered in the assessment of the sustainability of biogas production from POME, because the concept of sustainability is always based on at least three dimensions (environmental, social, economic) that influence each other in the long term.

Acknowledgements The authors would like to express gratitude for the financial support from the International Indexed Publication Grant (Hibah PUTI) Universitas Indonesia (contract number: NKB-2578/UN2.RST/HKP.05.00/2020) and the Provincial Government of Bangka Belitung Islands.

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